A NEW INTUITIVE MODEL OF FORCE AND MOTION

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This paper reports the preliminary results of research into the nature of students' intuitive models of motion of particles under the action of forces. Results from a small sample have indicated that a significant number of students have an intuitive model that is neither Newtonian or Aristotelian. This model is discontinuous: the nature of the motion changes as the force is increased
The data were collected by multichoice tests and by analysing verbal protocols, which were taken after the subject had sorted a number of cards depicting mass pulley systems into classes according to their motion.

Introduction and Background Literature.

This paper describes some preliminary results of research into student's intuitive models of motion. There are indications that many students have an intuitive model of the motion of a particle under the action of a force which differs from both the Newtonian and Aristotelian models.

The "inertia" intuition identified in this research is a discontinuous model allowing 3 phases of motion depending on the size of the applied force relative to the inertia of the body: 1. Static - no motion~ 2. Motion = constant velocity~ 3. Motion = acceleration.

During the course of investigating this intuition the subjects exhibited one or both of two other false intuitions. The "balance" intuition concerns a misconception about balance, and we believe this has not been reported in the literature. The subject argues that a mass pulley system is in equilibrium if the sum of the masses either side of some arbitrary point are equal, regardless of the configuration. The "height" intuition is known and concerns the effect of height on mass / pulley systems. There are two variations of this misconception. Some subjects argue that the gravitational force is greater on the lower mass, when two masses are at different heights. Other subjects argue that two equal masses attached to the ends of a light inextensible string passing over a massless frictionless smooth pulley will move until they are level.

The problem of students' intuitive models based on personal experience and at variance with scientific theory is well supported in the literature. Viennot (1979), Helm (1980), Watts and Zylbersztajn (1981) all identify an Aristotelian model of motion among the students of many nations and a wide age range. Fiengold et al (1991) found that many students retained their erroneous models even after instruction. Roper (1985) confirmed many of these findings and found that students at the end of their" A" level studies still held to their Aristotelian model.

Research Methods.

The investigation used two main methods: multiple choice tests; and a card sorting exercise, followed by taped (audio only) interviews.

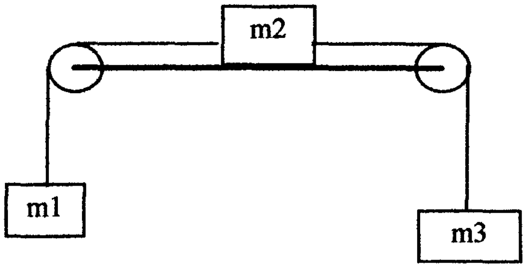

Figure 1 The 3 Mass Problem

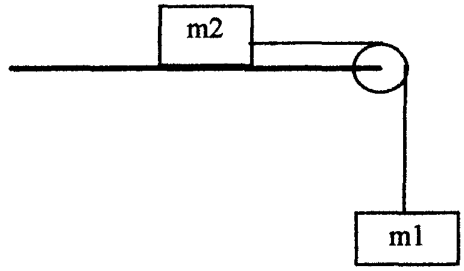

Figure 2 The 2 Mass Problem

Extensive use was made of the problems shown in Figures 1 and 2. In each case the subject was asked to classity the nature of the motion of the mass on the table if the system was released from rest. All surfaces and pulleys are assumed to be smooth, and pulleys and strings massless. Problems are identified as A(1, 5, lL), where A is the problem identifier and the triple refers to the 3 masses in the obvious way; the letter L indicates the lower hanging mass when the heights are different.

The Multiple Choice Tests

The initial evidence for the inertia intuition is taken from the results of a multiple choice test, which was administered to 18 "A" level students. The part of the test of interest consisted of three variations of the 3 mass problem: (1, 1,2), (1, 5, 2) and (1, 1000,2). In each case the correct response is "Accelerate Right". We anticipated that subjects exhibiting the inertia intuition would choose this response for the first problem, but classity the last case as stationary. (1, 5, 2) was thought to be a borderline case: subjects might choose any option depending upon the "strength" of the intuition. The inertia intuition was exhibited by some 27% ofthe subjects. In the event the results were complicated by the balance intuition, which caused two subjects to classity (1, 1,2) as stationary. The logic they applied was that the two 1 kg masses "balanced" the 2 kg mass. Ifwe ignore these two cases we have 5 subjects who thought the 1000 kg and 5 kg masses would remain stationary, and 4 who think the 1 kg mass will move at constant velocity.

A longer multiple choice test was administered to 27 Year 7 pupils in order to assess the prevalence of the inertia intuition before formal mechanics instruction. This consisted of 16 questions; all variations on the 2 or 3 mass problems. Five of the questions were selected to show evidence of the inertia intuition: 1000 kg on the table, with relatively small hanging masses (200 kg or less). These were classified as stationary by at least 63% ofthe subjects. Another problem involved the large mass on the table, but quite large hanging masses (1000, 1000,2000). This was borderline: 30% thought it would remain stationary, and 44% thought it would move at constant velocity. Where one of the hanging masses was significantly larger than the mass on the table (1, 1,5), 78% thought it would accelerate.

The Interview Evidence for the Inertia Intuition.

The interviews are ongoing. When this paper was written nine subjects had been interviewed, and there is some evidence of the inertia intuition in four of the cases. All the subjects were studying mathematics (including mechanics) at "A:' level and had completed at least two terms study.

Card	Problem	Correct	KB	JW(1)	JW(2)	SMT	DW
A	2, 5, 1	acc left	stat	cv left	stat	acc left	stat
B	2, 1, 1	acc left	cv left	acc left	acc left	acc left	acc left
C	1, 1K, 2	acc right	stat	stat	stat	acc left	stat
D	1C, 1K, 2C	acc right	cv right	stat	stat	cv right	cv right
E	2K,1K,1K	acc left	cv left	acc left	acc left	acc right	cv right
F	1L,1,2	acc right	acc right	cv right	acc left	cv right	cv right
G	2L,1,1	acc left	acc left	acc left	acc left	acc left	stat
H	1,1K,2L	acc right	acc right	stat	stat	acc right	cv right
I	2,1K,1L	acc left	stat	stat	stat	cv left	stat
J	1,2K,1	stat	stat	stat	stat	stat	stat
K	1,1,1	stat		stat	stat	stat	stat
L	1,1,1L	stat	cv right	stat	cv right	stat	acc left
M	0,1,1	acc right	_	cv right	cv right	stat	acc right
N	0,5,1	acc right	_	cv right	stat	acc right	cv right
O	0,10,1	acc right	_	cv right	stat	acc right	cv right
P	0,25,1	acc right	_	stat	stat	cv right	stat
Q	0,100,1	acc right	_	stat	stat	cv right	stat
R	0,1K,1	acc right	_	stat	stat	cv right	stat

Table 3 Card Sort Results

At the start of the interview the subject was asked to classify the motion of a number of 3 and 2 mass problems shown on cards. In the following extracts there is evidence for three distinct phases in the discontinuous model of motion. Where it was thought that it would help understanding the triple identifYing the problem has been added, but these are not part of the verbal protocols.

<u>Phase 1</u>

When the applied force is too small to cause motion. This is exhibited by several subjects, usually by classifYing cards showing 1000 kg on the table with relatively small hanging masses as stationary, because the hanging masses are not big enough to move the top mass. This is regardless of the fact that the hanging masses are not equal so there is a resultant force.

P1M OK, these cards here which is D(100, 1000, 200), J(1, 1000, 1), *R(1, 1000,* 2), 1(2, *1000, 1L) and C(1, 1000,* 2), *you said it would remain stationary. Would you like to tell me why?*

JW The weights on the table are far more heavy than those on the side.

P1M Right, so it's a case that the dangling masses are not enough to disturb it?

.JW No.

Phase 2.

When the subject considers that the resultant force is large enough to cause motion, but only at constant velocity. During this phase we often find that the height intuition interacts with the inertia intuition: the difference in height is perceived as the agent which provides the small increment in force needed to cause the phase change. The following extract is an example of this happening.

PlM ... This is D(JOO, 1000, 200) and F(JL, 1, 2) *with the three masses ... , why do you say they will go at a constant velocity?*
SMT F is because the 2 *kg is higher up than the* 1 *kg.*
PlM Right.
SMT So I thought that if it's released the 2 *kg would be sort of not accelerate as fast, so it would move at constant velocity. Since* 1 *kg is lower down.*
PlM OK, right, let'sjust ... just tell me whatwil/ happen then altogether. You know I release this thing from rest, and you say it will go right with a constant velocity, will it keep going right ..... Will it keep going at a constant velocity, or ..
SMT I was thinking when the two masses reach the same level it will start accelerating. PlM It'll start accelerating. So it'll go at a constant velocity until the masses are at the same level and you think that's because the ... just tell me again what did you say about the 2 *kg?*
SMT It's higher, the 1 *kg is lower down so it's harder to pull.*
PlM Right, OK. Now why did you say D(JOO, 1000, 200) would accelerate right? Sorry, move right at a constant velocity, my mistake?
. SMT Constant velocity?
PlM Yeah.
SMT Er, I was thinking that, er, 'cos the mass on the table is quite heavy. So would not be that e~ to accelerate

The intuition seems to be based on the everyday observations of the subject: heavy things are hard to move. In this extract SMT has been questioned about a pulley system with hanging masses of I kg and 2 kg and no mass on the table, which he said would accelerate. He is then asked why the addition of the mass on the table should cause the motion to change to constant velocity.

PlM That [the simple pulley system] would accelerate? But here we move at a constant velocity when we have got a mass on the table?
SMT I was thinking that the mass on the table might restrict the acceleration to some extent.
PlM The *mass on the table might restrict it to some extent, can we pick up on that point? Tell me how the mass on the table restricts it. What's the sort of, you know, what's the sort of property of the mass on the table that restricts it?*
SMT Well, I was going to say it's weight stopping it, but ....
PlM You think it's its weight?
SMT yes, ... there's a mass on the table and it 's heavy and it will be hard to move.

Phase 3.

When the subject considers that the resultant force is large enough to cause the system to accelerate. Typically we find that this happens when resultant force is significant compared with the weight of the mass on the table. In the following extract we can see the phase change from constant velocity and acceleration.

> *PTM ... OK, what if we had a similar situation to this, '" on cardM(O,* 1, 1), *and I make the hanging mass to be 10 kg, what would it do then do you think?*
> *JW It would accelerate downwards.*
> *PTM It would accelerate. So at 1 kg you think it would go at constant velocity, and if I increase the mass enough. ..*

Persistence of the Intuition

JW was interviewed again after some six weeks to investigate further his understanding of some of the basic concepts involved. He repeated the card sorting exercise during this second interview. The following protocol extract shows that he still believed the discontinuous model of motion, even though the first interview had concluded with a tutorial to discuss his errors.

> *PTM ... 1(2, 1000, 1L), why do you say I will stay still?*
> *JW 'Cos the mass in I is not great enough to move the object on top.*
> *PTM AndwhataboutJ(1, 1000,* 1)?
> *JW Again the mass is not big enough.*
> *PTM And M(O,* 1, 1) *you say will go right with a constant velocity.*
> *JW It's lower down, and it will just drag it down, it will just pull it.*

The Intuition in a Successful Subject.

Even though he sorted the cards successfully, subject m admitted that he found the cards with 1000 kg on the hardest to deal with, as the following extract shows. Regarding H(l, 1000, 2L) he states *"Yes, it 's because er .. I don't think having one lower than the other really affects it, it's because that is so heavy. You think ... if you apply f = ma you realise it will move, but you still think that if it is that heavy it doesn't matter - there will be a time when you won't be able to move it. "*

The Height and Balance Intuitions.

While investigating the inertia intuition two other intuitions were apparent. In each case they affected the results of the card sorting exercise, either by interacting with the inertia intuition, or by giving unexpected results. The first of these is the height intuition, which has been recorded in the literature. This has two variants discussed above. We have seen that the second variant can be the agent needed to cause the small changes in force required to cause a phase change in the discontinuous model of motion. The second intuition, that concerning balance has not been reported before. In this the subject argues that a mass pulley system is in equilibrium if the sums of the masses either side of some arbitrary point are equal, regardless of the configuration of the masses. For example SMT classified M(O, 1, 1) as stationary because *"I think it is because the two masses have got the same weight.* " These intuitions mean that care must be taken when choosing the size and configuration of masses for the problems used to investigate the inertia intuition.

Conclusions and Discussion

There is evidence from this small sample that some students have an intuitive model of the motion of a body under the action of a force that is more complicated than that usually discussed in the literature. The model is discontinuous: the nature of the motion changes as the force increases. We may define the intuition as: *When a force acts on a particle, the nature of the motion depends on the magnitude of the force. With increasingforce the phases of the motion are: Phase* 1, *when the particle remains stationary until the force reaches a certain magnitude; Phase* 2, *when the particle moves with a constant velocity, until the force is increased sufficiently; Phase* 3, *when the body accelerates.*

The protocols have not yet revealed if the initial motion obeys $F = kv$, but the acceleration phase appears to obey Newton's Second Law. The protocols have not revealed the magnitudes offorce needed to change the nature of the motion. Subjects do not necessarily exhibit all the phases. In this small sample there is no evidence for Phase 1 in the protocols of subject SMT, for example.

There are however a number of unanswered questions, for example:

- Is this model transitional between the Aristotelian and Newtonian models?
- How general are these results across the student cohort?
- How general are these results for different types of problems?
- To what extent does this qualitative analysis of a mechanics problem affect the outcome of quantitative analysis by the same subject?

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